ON THE NATURE OF VIBRATORY MOTIONS[1]

III.

Experiments by which Compound Sounds are analysed by viewing in a Rotating Mirror the Vibrations of König's Manometric Flames.

TAKE a piece of pine board, A, Fig. 15, 1 inch (25 millimetres) thick, $1\frac{1}{2}$ inch (38 millimetres) wide, and 9 inches (22·8 centimetres) long. One inch from its top bore with an inch centre-bit a shallow hole $\frac{1}{8}$ inch deep. Bore a like shallow hole in the block B, which is $\frac{3}{4}$ inch thick, $1\frac{1}{2}$ inch wide, and 2 inches (51 millimetres) long. Place a $\frac{1}{2}$-inch centre-bit in the centre of the shallow hole in A and bore with it a hole through the wood. Into this fit a glass or metal-tube, as shown at E. Bore a $\frac{3}{16}$-inch (5 millimetres) hole obliquely into the shallow hole in B, and into this fit the glass tube C. Then bore another $\frac{3}{16}$-inch hole directly into the shallow hole in B. Put a glass tube in a gas or spirit flame and heat it red-hot at a place about two inches from its end. Then draw the tube out at this place into a narrow neck. Make a cut with the edge of a file across this narrow neck, and the tube will readily snap asunder at this mark. Then heat a place on the tube in a flame, and here bend it into a right angle, as shown at D, Fig. 15. Now fit this tube into the hole just made, as shown at D. These tubes may be firmly and tightly fitted by wrapping their ends with paper coated with glue before they are forced into their holes.

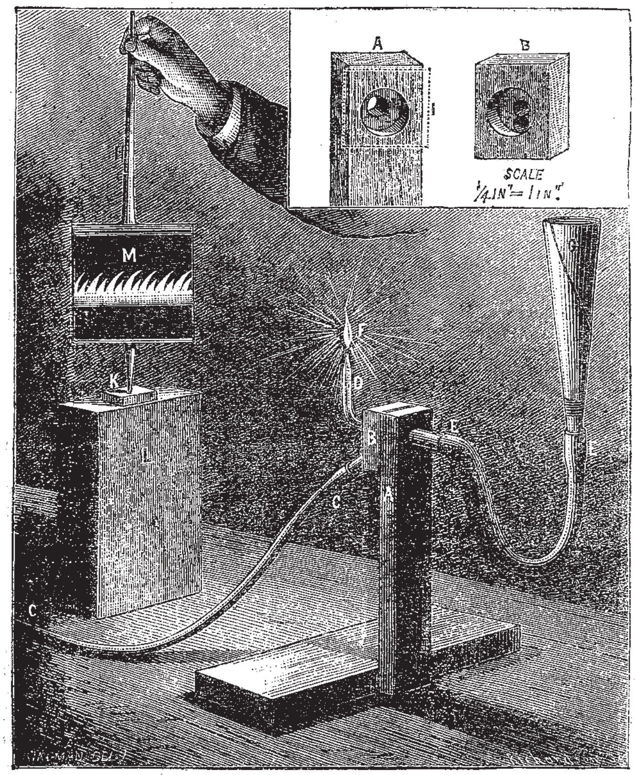

FIG. 15.

Get a small piece of the thinnest sheet rubber you can find, or a piece of thin linen paper, and, having rubbed glue on the board A around the shallow hole, stretch the thin rubber, or paper, over this hole and glue it there. Then rub glue on the block B, and place the shallow hole in this block directly over the shallow hole in A, and fasten B to A by wrapping twine around these blocks. Thus you will have made a little box divided into two compartments by a partition of thin rubber. Fasten the rod A to the side of a small board, so that it may stand upright.

Attach a piece of large-sized rubber tube to the glass tube E, and into the other end of the tube stick a cone, made by rolling up a piece of cardboard so as to form a cone 8 inches long and with a mouth 2 inches (51 millimetres) in diameter.

Now get a piece of wood 1 foot long, 4 inches wide, and $\frac{1}{4}$ inch thick. Out of this cut the square, with the two rods projecting from it, as shown at M. The lower of these rods is short, the one above the square is long. Cut the end of the shorter rod to a blunt point, and with this point make a very shallow pit in the piece of flat wood K for the rod and square to twirl in. Glue the piece of wood K on the end of a brick, L. Get two pieces of thin silvered glass, each 4 inches square, and, placing one on each side of the square M, fasten them there by winding twine around the top and bottom borders of the mirrors.

Experiment 16.—Through a rubber tube lead gas to C. It will go into the left-hand partition of the box and will come out at F, where you will light it. Now place the mirror-rod in the shallow pit in K, and hold the mirror upright so that you may see the flame F reflected from its centre.

Hold the rod upright and twirl it slowly between the thumb and forefinger, which should point downward and not horizontally, as shown in the figure. The flame appears in the mirror drawn out into a band of light with a smooth top-border. While twirling the mirror put the cone to your mouth and sing into it. The sonorous vibrations enter the side A of the box, and, striking on the thin rubber, force this in and out. When it goes in a puff of gas is driven out of the other partition, B, of the box, and the flame F jumps up. When the sheet of rubber vibrates outward it sucks the gas into the box B, and the flame F jumps down. Therefore, on singing into the funnel, you will see in the mirror the smooth top-border of the luminous band broken up into little tongues or teeth of flame, each tooth standing for one vibration of the voice on the rubber partition.

Place a lamp-chimney around the flame, should the wind from the twirling mirror agitate it, and be careful not to have the flame too high.

Experiment 17.—Another way of showing the vibrations of the flame is to burn the jet of gas at the end of a glass tube stuck into the end of a rubber tube attached to F. Now sling the tube round in a vertical circle, and you have an unbroken luminous ring; but as soon as you sing into the cone this ring breaks up into a circle of beads of light, or sometimes changes into a wreath of beautiful little luminous flowers, like forget-me-nots. To make this experiment you will be obliged to have a tube with a larger opening than that at F.

This instrument will afford you many an hour of instruction and amusement. We have only space to show you a few experiments. Others will suggest themselves whenever you use it.

Experiment 18.—Sing into the funnel the sound of *oo* as in p*oo*l. After a few trials you will get a pure simple sound, and the flame will appear as in Fig. 16. Some voices get this figure more readily by singing E.

Experiment 19.—Twirling the mirror with the same velocity, gradually lower the pitch of the *oo* sound till your voice falls to its lower octave, when the flame will appear as in Fig. 17, with half the number of teeth in Fig. 16, because the lower octave of a sound is given by half the number of vibrations.

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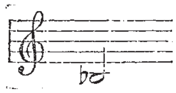
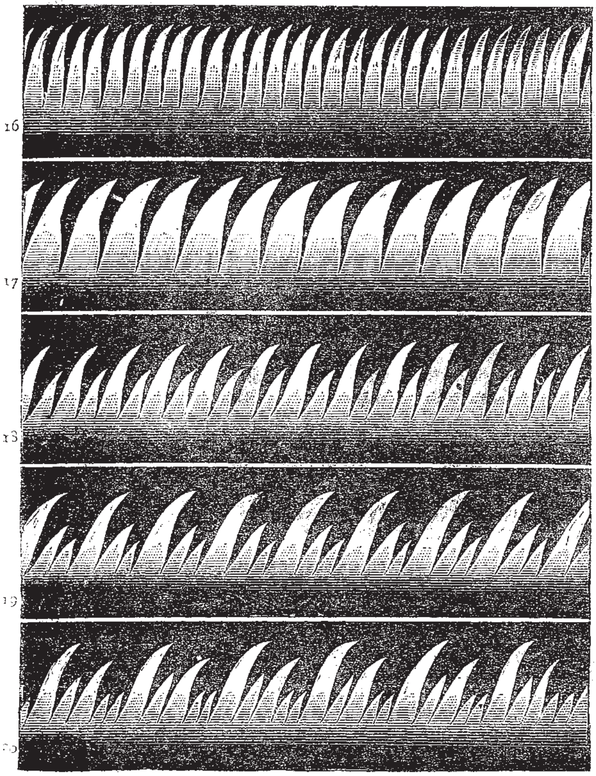
[1] From a forthcoming work on "Sound: a Series of Simple, Entertaining, and Inexpensive Experiments in the Phenomena of Sound, for the Use of Students of every Age." By Alfred Marshall Mayer, Professor of Physics in the Stevens Institute of Technology. Communicated by the author. (Continued from p. 556.)

Experiment 20.—Sing the vowel-sound *o* on the note



and you will see Fig. 18 in the mirror. This evidently is not the figure that would have been made by a *simple* vibration. It shows that this *o* sound is compound, and formed of two simple sounds, one the octave of the other. The larger teeth are made by every alternate vibration of the higher simple sound acting with a vibration of the lower, and thus making the flame jump higher by their combined action on the membrane.

Experiment 21.—Fig. 19 appears on the mirror when we sing the English vowel *a* on the note f.



FIGS. 16, 17, 18, 19, 20.

Experiment 22.—Fig. 19 appears on the mirror when we sing the English vowel *a* on the note c.

Examine attentively Fig. 19. This shows that the English vowel *a* sung on f is made up of two combined simple vibrations. One of these alone would make the long tongues of flame, but with this simple vibration exists another of three times its frequency; that is, the vibration of greater frequency is the 3rd harmonic of the slower. As the slower vibration, making the long tongues of flame, is f, the higher must be *c''* of the second octave above f. Each third vibration of this higher harmonic coincides with each vibration of f; hence each third tongue of flame is higher than the others.

Experiment 23.—In like manner the student must analyse Fig. 20 into its simple sonorous elements. Then he should, with the vibrating flame, examine the peculiarities of the various voices of his friends, and make neat and accurate drawings of the flames corresponding to them, so that he may analyse them at his leisure.

Experiment 24.—Blow your toy trumpet into the paper cone gently, and then strongly, and observe that the sound given by the trumpet is a complex one. Try if you cannot get a flame somewhat like the trumpet gives by singing *ah*, through your nose, into the cone.

The student will soon find that different persons, in singing the same note, as nearly alike as they can, will produce flames of very different forms. This is because the voices differ in the number and relative intensities of the simple sounds which form them.

Another cause of the different forms of flame obtained by different experimenters is due to the fact that they have used different lengths of tube leading from the cone to the membrane.

Experiment 25.—The fact can be readily shown by singing the same compound sound through different lengths of tube leading from the cone G to the membrane.

Terquem's Experiment, in which König's Flame is used instead of the Ear, and thus the Motions of a Vibrating Disk are made Visible.

The method of analysing the motions of a vibrating plate with the paper cone and tube applied to the ear, which has been used by us for a long time, has quite recently been adapted to M. König's flame by Prof. Terquem, of Lille, who has thus made these motions visible to the student, and has given us a charming experiment.

On how we Speak, and on the Talking Machines of Faber and Edison.—How we Speak.

The little musical instrument with which we sing and speak is formed of two flexible membranes stretched side by side across a short tubular box placed on the top of the windpipe. This box is made of plates of cartilage, movable on each other, and bound together with muscles and membranes.

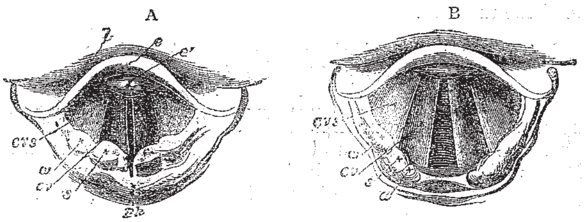


FIG. 21.

FIGS. A and B.—Views of the human larynx from above as actually seen by the aid of the instrument called the laryngoscope. Fig. A.—In the condition when voice is being produced. Fig. B.—At rest, when no voice is produced. *e*, epiglottis (foreshortened); *cv*, the vocal chords; *cvs*, the so-called false vocal chords, folds of mucous membrane lying above the real vocal chords; *a*, elevation caused by the arytenoid cartilages; *s*, *w*, elevations caused by small cartilages connected with the arytenoids; *l*, root of the tongue.

The top of the windpipe is formed of a large ring of cartilage, called the *cricoid* (ring-shaped) cartilage. Jointed to this is a broad plate of gristle, called the *thyroid* (shield-shaped) cartilage. This cartilage is bent into the shape of a V. The legs of this V straddle over the cricoid and are jointed to its outer sides. The peak of the V stands up and points toward the front of your throat. You can feel it, as it is the "Adam's apple." On the back of the upper edge of the cricoid ring are jointed two small pointed cartilages, known as the *arytenoid* (funnel-shaped) cartilages. Stretching from these to the inner sides of the legs of the V of the thyroid are two membranes, one to each leg. These are the *vocal chords.*

When the point of the thyroid is not pulled down these membranes are lax, and the breath from the windpipe passes freely between them and does not make them vibrate. (*See* B of Fig. 21.)

But when the peak of the thyroid is pulled down by its muscles the vocal chords are stretched. At the same time the arytenoid cartilages move nearer each other, and the thin, sharply-cut edges of the vocal chords are brought parallel and quite close to each other, as is shown in A of Fig. 21. If the air is now forced through this narrow slit (called the *glottis*), the vocal chords vibrate just like the tongue in our toy trumpet, or like the reed in any reed-pipe. A puff of air passes between them; they separate; immediately afterward they come close together and the current of air is stopped. They again open, another puff goes into the cavity of the mouth, and then they close together again. Thus the glottis opens and closes with a frequency depending on the degree of stretch on the vocal chords.

Our experiments with König's flame have shown how composite are the sounds of the human voice. The quality of a voice depends on the number and relative intensities of the simple sounds which build it up.

SPEECH is voice modified and modulated by the movements of the parts of the cavity of the mouth, of the tongue, and lips.

The oral cavity is made larger or smaller, longer or shorter, and thus, resounding to some lower or higher harmonic of the voice, makes the others feebly heard.

Experiment 26.—If you form your speaking organs to say *o*, and then take your vibrating A-fork and hold it before your lips, you will hear the cavity of the mouth resounding to this sound. On changing the vocal organs to say *e* the resonance ceases.

All the vowel sounds are formed by a steady voice modified by the resonance of the different sizes and shapes given to the oral cavity.

The consonants are made by obstructions placed at the beginning or end of the oral sounds, by the movements of the tongue and lips; but, as this is a book of experiments, I leave you to inform yourself by experiments as to these matters.

Experiments in which a Toy Trumpet Talks and a Speaking Machine is Made.

Experiment 27.—Sing *ah*, and while doing so quickly open and shut your lips twice. These two sudden obstructions to the sound have made you say *mama*. If you will observe attentively the motion of your mouth you will see that for the last syllable of mama you open your mouth wider and keep it open longer than for the first syllable.

Experiment 28.—This is all we have to know to make our toy trumpet talk. You already have seen that its sounds, like those of the human voice, are made by puffs of air. These pass the reed every time it goes above or below the oblong hole in the plate in which it vibrates. Your experiments with König's flame have told you that the sounds of the voice are similar—that both are highly composite.

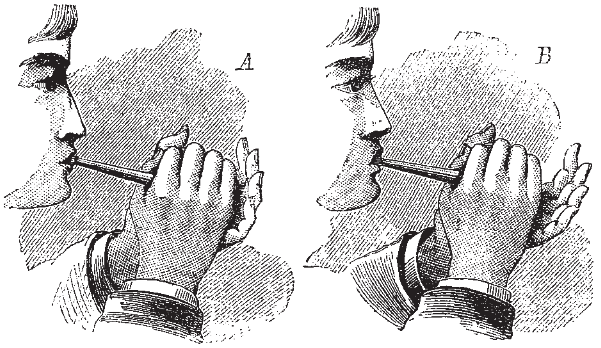


FIG. 22.

Let, then, the vibrating reed in the trumpet stand for your *vocal chords*. To get a resonant cavity like the *mouth* make one between your two hands, as shown in A of Fig. 22. The funnel of the trumpet is placed inside this cavity with the tube coming out in the crotch between the thumb and forefinger. The lips we will form of the fingers of one hand. By raising these together, more or less, from the other hand we can make a larger or smaller opening into the cavity between the palms of the hands, and thus get articulation.

Now blow into the trumpet as though you were speaking *mama* into it, so that you may make it sound twice, each sound lasting just as long as the sounds in mă and mā. While making the first sound, raise the fingers as high as is shown in A; while making the second, raise them as high as is shown in B. The trumpet talks and says *mama* quite plainly.

Experiment 28.—Let us make a talking machine. Get an orange with a thick skin and cut it in halves. With a sharp dinner-knife cut and scrape out its soft inside. You have thus made two hemispherical cups. Cut a small semicircle out of the edge of each cup. Place these over each other, and you have a hole for the tube of the trumpet to go out of the orange. Now sew the two cups together, except a length directly opposite the trumpet, for here are the *lips*. A pea-nut makes a good enough nose for a baby, and black beans make "perfectly lovely" eyes. Take the baby's cap and place it on the orange, and try if you can make it say

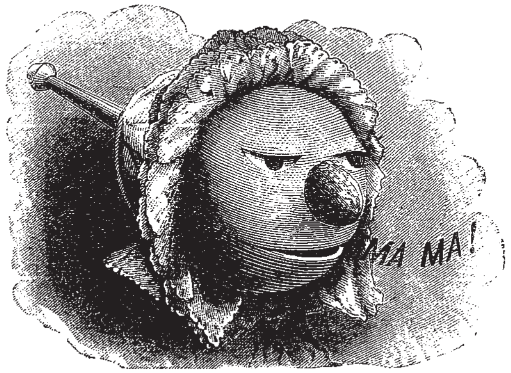


FIG. 23.

Faber's Talking Machine.

These simple experiments show the principles followed in the construction of the celebrated talking machine of Faber of Vienna. A vibrating ivory reed, of variable pitch, forms its vocal chords. There is an oral cavity whose size and shape can be rapidly changed by depressing the keys on a key-board. Rubber, tongue, and lips make the consonants. A little windmill turning in its throat rolls the *r*, and a tube is attached to its nose when it speaks French. This is the anatomy of this really wonderful piece of mechanism.

ELECTRIC LIGHTING

ALL the papers are still much occupied with correspondence about the electric light, the extent to which it may be brought into public use, and its possible effect upon the use of gas and upon gas companies. Many writers display much ignorance both as to the scientific and economical bearings of the matter; the most important communication on the subject that has appeared is the letter from Dr. C. W. Siemens in the *Times* of the 12th inst. Dr. Siemens writes as follows :—

> The intelligence flashed through the Atlantic cable a few days since to the effect that Mr. Edison, the ingenious inventor of the phonograph, &c., had succeeded in dividing electric currents